Green River crossing on the Oregon Trail, Wyoming

Chapter 6: Components of the Iterative Phase of Adaptive Management

6

Adaptive management as we describe it in this guide calls for the elements in Chapter 5 to be folded into an iterative process of decision making and learning (Figure 2.2). It also is useful to interrupt the technical learning cycle periodically in order to reconsider the set-up elements and incorporate any changes that may be needed if perspectives and values change over the course of the project.

In this chapter we revisit the processes of the iterative phase of adaptive management – namely, decision making, post-decision monitoring, assessment of monitoring data, learning and feedback, and institutional learning. Again, we use examples from the four thematic areas of climate change, water resources, energy development, and human impacts on the landscape to illustrate the iterative phase. Summaries of the examples are found the appendix.

6.1. Decision making

We described earlier how adaptive management focuses on management in the face of uncertainty, with the potential to improve management as our understanding of its consequences grows over time. Here we consider the actual process of adaptive decision making, with decisions at each point in time that reflect the current level of understanding and anticipate the future consequences of decisions.

The actual process of adaptive decision making varies depending on the particular project. An institutional framework consists of one or more decision makers along with other stakeholders who provide advice and guidance. Decision making at each decision point considers management objectives, resource status, and knowledge about consequences of potential actions. Decisions are then implemented by means of management actions on the ground.

In some cases the decision process includes only a small number of managers who, for example, adjust water flows or follow mowing schedules on a wildlife refuge. Other decision processes call for a more formal structure of public input, information sharing, and review of proposed actions. For example, a highly structured process is mandated by the National Environmental Policy Act, which calls for engagement of stakeholders and the public, communication of management alternatives, publication of relevant documents, and a final record of decision or other decision documents.

Climate change. Because of the far-reaching impacts of climate change and the broad spectrum of potential stakeholders, decision making for climate change problems will probably involve a rather structured process of stakeholder input that includes federal, state, and perhaps municipal interests. Mitigation actions might focus on regulatory actions, permitting, tax incentives, or policies to reduce greenhouse gas emissions. Adaptation actions might include direct interventions (e.g., species translocation, creation of corridors) as well as regulatory and other policy responses.

Water resources. Water management almost always involves joint consultation and input from stakeholders, often a board of stakeholders with divergent perspectives and values who make recommendations to a water authority. The authority is frequently a government agency such as the Bureau of Reclamation or the Army Corps of Engineers, which presides over the water board. Management actions are often required at regular intervals as determined by seasonal precipitation, snowmelt, and other patterns. Uncertainty about management impacts is addressed by means of experimental interventions (e.g., water releases) that are implemented over time, with follow-up monitoring between interventions to provide new information for future decisions.

Energy. Energy development typically involves federal and state authorization and oversight of permits. Permittees are almost always private energy interests who take on the responsibility for infrastructure development and facility operations. Decision making includes review and approval of proposals for the siting, development, and operation of energy facilities. Decisions about siting new facilities can use information collected at existing facilities, whereas decisions about facility operations can use single-site information collected over time, as well as information collected at other sites.

Human/natural interface. Approaches to decision making in this thematic area vary widely. With some notable exceptions, the elaborateness of the decision-making process is linked to the ecological or geographic scale of the problem. For example, annual decision making on a small nature preserve might involve a few resource managers who informally interpret information collected yearly on the preserve and discuss its relationship to the management alternatives. On the other hand, decision making at a regional level would need a more structured and formal process involving federal, state, and non-government interests in joint fact finding and collaborative decision making.

Examples of decision making

Laysan duck translocation and sea level rise

The Laysan duck is an endangered species with only two populations on remote low-lying Pacific atolls. The species' entire range covers less than 9 square kilometers. To increase chances of species survival, Fish and Wildlife Service managers and U.S. Geological Survey scientists are preparing a framework to manage the translocation of ducks adaptively in order to establish other breeding populations in the northwestern Hawaiian islands.

Managers will collaborate on operational decisions such as where and when to translocate ducks, contingent upon duck population and habitat status. Quantitative decision analysis with stochastic optimization or simulation methods will support decision-making and management.

Glen Canyon hydroelectric dam

The Glen Canyon Dam on the Colorado River was established primarily for water storage and hydroelectric power production, but operations of the dam led to adverse impacts on downstream resources, including endangered native fish downstream in the Grand Canyon. Beginning in 1996, adaptive management principles have been used to help inform changes in dam operations and other activities undertaken to improve resource conditions in downstream areas including Grand Canyon National Park. The adaptive management process works within a legal process on the Colorado River, with changes in dam operations that are designed to improve conditions

for endangered species and the downstream ecosystem. Other activities include experimental translocation of endangered fish to other tributaries in order to assess the feasibility of establishing additional breeding populations. The Adaptive Management Work Group, a federal advisory committee, makes recommendations to the Secretary of the Interior on the operations of Glen Canyon Dam.

Cape Cod National Seashore wind turbines

The Cape Cod National Seashore is planning to power some park facilities sustainably with wind turbines to reduce greenhouse gas emissions, within the constraint of conserving park resources (i.e., unacceptable impacts on birds and bats must be avoided). Adaptive management will be used to decide whether and when to adjust or shut down operations of the turbines. The park superintendent will make decisions with input from the Fish and Wildlife Service, the Massachusetts state endangered species program, and the public, contingent on bird and bat mortality resulting from operation of the turbines.

Wyoming Landscape Conservation Initiative

In the Wyoming Landscape Conservation Initiative, adaptive management is used to conserve and enhance wildlife habitat, within the constraint of developing oil and gas resources on predominantly federally managed land. A five-member coordination team is responsible for conservation planning and implementation of adaptive management strategies, and for managing fiscal and logistic operations. Plans for the initiative call for adaptive decision making for habitat conservation and other activities, but not for leasing for energy development.

Adaptive harvest management

Adaptive harvest management was developed to deal with uncertainties about the regulation of sport waterfowl hunting in North America. Early each year, the Fish and Wildlife Service announces its intent to establish waterfowl hunting regulations and provides the schedule of public rule-making. The agency director appoints a Migratory Bird Regulations Committee with representatives of the waterfowl flyway councils, which presides over the process and is responsible for regulatory recommendations. The committee directs a technical working group of biologists to use dynamic optimization to identify optimal regulatory policies that account for breeding population size, environmental conditions, and the current level of understanding. Once the regulations are approved by the director, they provide outside limits (on hunting season length and bag limit) within which the states select their state hunting seasons.

6.2. Follow-up monitoring

Monitoring, a key component in all applications of adaptive management, provides information to estimate resource status, informs decision making, and facilitates evaluation and learning after decisions are made. In the context of adaptive management, monitoring is an ongoing activity, conducted according to the protocols developed in the set-up phase. In some situations it is undertaken each time a decision is made, for example, when managing species with annual life cycles. In other cases monitoring may be undertaken only after several management interventions, for example, when an ecological system takes a long time to exhibit a response to management.

Project needs determine the timing of monitoring. In many adaptive management applications, monitoring is conducted at fixed and regular intervals. Monitoring can also be applied irregularly, especially if it is tied directly to available funding or if it targets extreme events or unusual disturbances of the resource. In one approach to timing a monitoring effort, monitoring is treated as a part of the decision making process itself, with the decision about whether to monitor at each point in time depending on the status of the resource (estimated from the most recent monitoring effort) and the level of structural uncertainty at that time. For example, a project using this approach might stipulate the monitoring of a population only if its abundance is low and there is a high degree of uncertainty about survival or reproductive potential.

Monitoring can be a highly refined process involving experts and strong controls on field data collection. Alternatively, it can be more loosely structured, perhaps involving a cadre of amateurs who collect the data. In either case, the monitoring program must be carefully designed to ensure a tight connection between management objectives and specific monitoring metrics and protocols so that the data collected are relevant to assessment, learning, and future decision making. Logistical and cost considerations include the time and effort required to get to field sites, the workload per person in the field, the process of recording and verifying field observations, and the amount of training and preparation of people collecting data. Attention to the details of who collects data, and how, are critical to successful resource monitoring.

Climate change. For problems involving climate change, environmental conditions must be tracked by ongoing monitoring in order to determine the direction and variability of environmental change. For monitoring the effects of mitigation and adaptation, variants of a "before versus after and control versus impact" design can help to isolate the effect of an intervention while accounting for changes in environmental conditions. Logistical considerations will depend on the type of problem and interventions. When a project involves monitoring activities across a large area, protocols must be clearly established and personnel must be carefully trained to ensure comparable results.

Water resources. Post-decision monitoring of water resources is usually organized around sequential management interventions and the need to compare their effects over time. Extensive aquatic systems that include both upstream and downstream habitats and conditions present special challenges for collecting and managing data. Water resource monitoring may include acquisition, installation, and maintenance of stream gages and other specialized equipment.

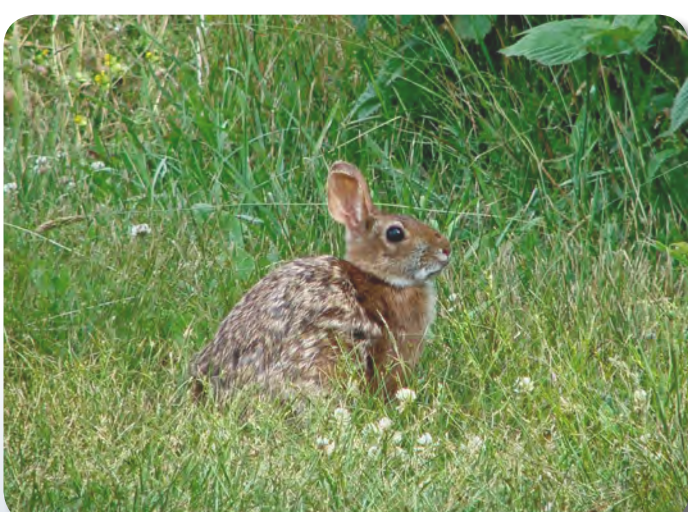
Energy. In many energy projects, private entities take responsibility for collecting and analyzing data as part of the permitting process. Under these circumstances there are requirements from the Data Quality Act for monitoring protocols, quality assurance and quality control, and personnel training. In adaptive management projects there also is an obligation to share data and assessment results among stakeholders so that adaptive adjustments can be made as impacts are recorded. When data are collected from different sites, standards need to be in place for consistency and comparability.

Human/natural interface. Monitoring activities under this theme are based on the type of project. All the logistical and operational issues mentioned in the introduction to this section may be relevant. Special concerns are the accessibility of sampling locations and the detectability of organisms at sample sites. Flexibility is needed in order to adjust monitoring protocols when some field locations become inaccessible. Because fish and other wildlife can be difficult to observe in natural settings, a statistical treatment of detectability should be incorporated into protocol designs when monitoring these resources. People who collect data may need to be trained in field procedures (e.g., how to estimate distance or wind speed; how to identify bird songs).

Examples of follow-up monitoring

New England shrub habitats on national wildlife refuges

Shrub communities on wildlife refuges in the northeast support migrating land birds and the New England cottontail rabbit, a candidate for listing under the Endangered Species Act. Fish and Wildlife Service managers are using adaptive management to control the invasive plants that degrade native shrub communities and reduce the food resources required by rabbits and birds. Refuge biologists train seasonal field staff and supervise a monitoring effort that targets a number of metrics related to plant and wildlife composition and abundance. Pellets are collected for cottontail surveys by a two-person team three times each winter, and mapping-grade GPS units are used to relocate points each year.



Bird surveys are conducted during the fall migration (September – October) over 8 to 10 person-days for each refuge, and vegetation surveys including berry counts are conducted over 12 to 14 person-days. Stem counts are made after leaves drop, and can take a week for a team of four biologists. Each type of monitoring has a time window that allows for variable weather conditions.

Adaptive harvest management

Adaptive harvest management was developed to deal explicitly with multiple sources of uncertainty in the regulation of sport waterfowl hunting in North America. Each spring, duck abundance and habitat conditions are monitored in over 5 million square kilometers of breeding habitat, with 89,000 kilometers of aerial transects. Ground surveys are conducted on a subset of the aerial transects to estimate the proportion of birds that are undetected from the air. The central portion of the breeding range is surveyed again in mid-summer to estimate the number of duck broods, and to assess the progress of the breeding season. These surveys have been operational since the 1950s, and they provide critical information for setting annual duck-hunting regulations. Federal and state biologists who are carefully trained in species identification and field techniques participate in these surveys.

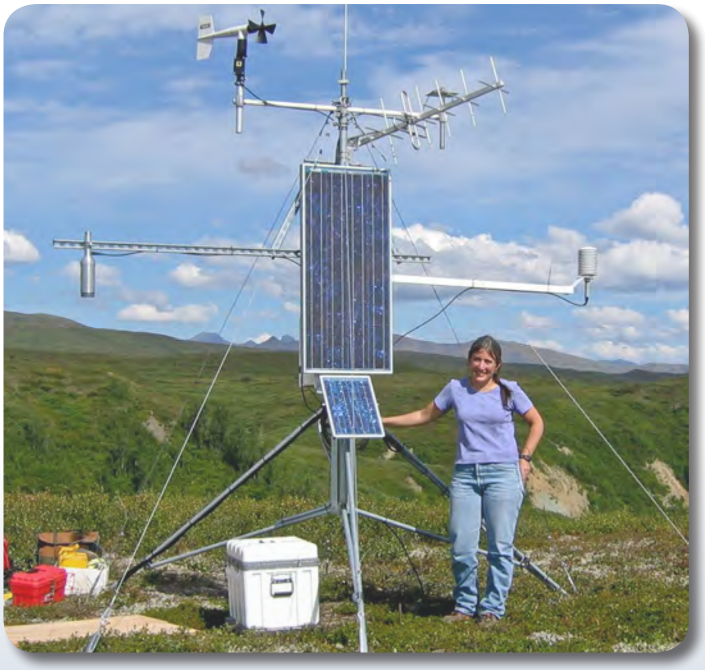
Waterfowl are also monitored through a large-scale banding program in which individually numbered leg bands are placed on over 350,000 birds annually, usually just before the hunting season. A waterfowl harvest survey is conducted each year via a mail questionnaire, which is completed by a sample of 30,000 to 35,000 waterfowl hunters across the United States. In addition to the questionnaire, about 8,000 hunters send in wings or tails of harvested birds so that the species and demographic structure of the harvest can be determined.

6.3. Assessment

In an adaptive management project, the data produced by monitoring are used along with other information to evaluate management effectiveness, understand resource status, and reduce uncertainty about management effects. Learning is promoted by comparing predictions generated by the models with data-based estimates of actual responses. The similarity between predicted and observed responses is used to judge model adequacy and thereby improve understanding. Monitoring data can also be compared with desired outcomes in order to evaluate the effectiveness of management and measure its success in attaining management objectives. In addition, monitoring data are used to estimate particular resource attributes and compare projected costs, benefits, and impacts of management alternatives for future decision making.

It is not uncommon for the assessment component of adaptive decision making to be underemphasized or under-resourced, especially if adaptive management is viewed simply as sequential decision making interspersed with monitoring. A common, though unjustified, assumption is that the monitoring data "speak for themselves" and require little if any analysis. In contrast, we emphasize how important it is to analyze monitoring data in learning-based management. But the staff time and other resources needed for this task should not be underestimated.

Climate change. Assessment in climate change includes evaluation of resource responses to mitigation and adaptation actions, by comparing predicted responses with observations from monitoring. Because climate may change unpredictably, it is important to include



an analysis of the potential for changing patterns in environmental conditions. This might involve different climate models or scenarios, with analysis of management strategies to determine which can best meet objectives in the face of uncertainty about future climate conditions. Dealing with potentially unstable climate and resource conditions, and the uncertainties associated with them, presents a serious challenge.

Water resources. Because water systems are fundamentally dynamic and influenced by environmental conditions and management actions, an adaptive management framework of sequential decision making and learning applies naturally to many water projects. Assessment can often be fairly straightforward, with an evaluation of water interventions, analysis of potential outcomes of management options, and comparison of predicted and observed patterns of change in water conditions.

Energy. Assessment of energy projects focuses on the analysis of data on the impacts of siting, infrastructure, and operations of energy facilities. Assessments might include estimating parameters such as mortality, reproduction, and migration rates of animals and plants affected by energy development. Other assessments could involve a comparison of resource conditions before and after energy development, by investigating attributes such as the distribution and abundance of species or the fragmentation and disturbance of landscapes.

Human/natural interface. Assessments for this broad class of problems can include a great many analyses, such as comparing effects of different management actions on resources, or evaluating the effectiveness of different strategies in achieving objectives. Assessment may also focus on learning, as in the comparison of predicted responses to management and actual responses recorded by field monitoring. Analyses may focus on the statistical association of resource and socio-economic data.

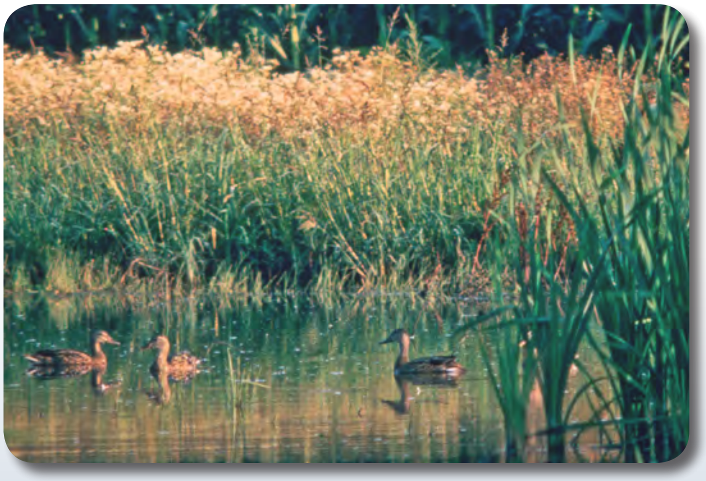
Examples of assessment

New England shrub habitats on refuges

Shrub communities on wildlife refuges in the northeast support migrating land birds and the New England cottontail rabbit, a candidate for listing under the Endangered Species Act. Fish and Wildlife Service managers are using adaptive management to control the invasive plants that degrade native shrub habitats. Assessments focus on restoration objectives, and monitoring data are used to track progress toward objectives (control of invasive plants and restoration of shrub community integrity), to determine the current status of the shrub communities and fauna of interest, and to make comparisons with predictions of the models aligned with low- and medium-intensity treatments. The comparison between observed and predicted metrics allows for updated measures of confidence in the two kinds of treatment used to restore the shrub community.

Prairie pothole restoration

The Minnesota Private Lands Program (part of the National Wildlife Refuge System) and other federal partners support restoration of privately owned small prairie pothole wetlands that were converted to agriculture. Adaptive management is being used for hydrological



restoration, sometimes combined with sediment removal. Evaluation focuses on the effectiveness of the management alternatives (hydrology restoration alone versus in combination with sediment dredging) in maximizing wetland quality. Technical analyses include assessment of expected changes in metrics for each of the alternative treatments, and updates of confidence weights for the competing models by comparing predicted versus observed pothole changes.

Vernal pools and amphibians

Landscape changes have degraded ephemeral vernal pools in the eastern United States. Potential impacts due to climate change could further stress vernal pools, specifically by altering hydroperiod length and water depth. This could lead to the decline of many amphibians, such as wood frogs, that depend on vernal pools for breeding. Management of vernal pools may become necessary to ensure adequate habitat for breeding frogs, especially near the southern edge of the range where multiple years of reproductive failure have produced documented declines. Biologists are evaluating whether direct manipulation of pool structure and water retention (e.g., by use of impermeable liners) can increase amphibian colonization and breeding success. Annual monitoring of egg masses, late-stage tadpoles (an indicator of successful breeding) and breeding adults allows biologists to identify ponds for direct manipulation. Field data are also used for comparisons with the predicted responses to management and anticipated climate patterns.

Florida scrub-jay habitat

The Florida coastal scrub ecosystem is highly modified by fragmentation and fire suppression, which has resulted in significant decline of endemic species like the endangered Florida scrub-jay. To measure progress toward restoration of a mosaic of successional stages following fire and mechanical treatments, managers annually monitor vegetation structure from aerial photographs and conduct presence/absence surveys for scrub-jays. Data collected at the patch level are used to describe current resource status. By comparing actual status with the status predicted by linked habitat transition–occupancy models, managers are able to learn how fire or mechanical treatments affect vegetation transition rates, and thereby reduce a key uncertainty in managing for improved habitat for scrub-jays.

Adaptive harvest management

Adaptive harvest management was developed to deal with uncertainties in the regulation of sport waterfowl hunting. Each year assessments incorporating different models of waterfowl populations and management alternatives are used to support decision making, evaluation, and learning. Regulatory decisions are based on comparisons among potential outcomes of different actions. Learning is promoted by comparing predictions from each of four population models with waterfowl population estimates derived from monitoring. Comparing outcomes with population objectives is used to evaluate how well harvest objectives are being met.

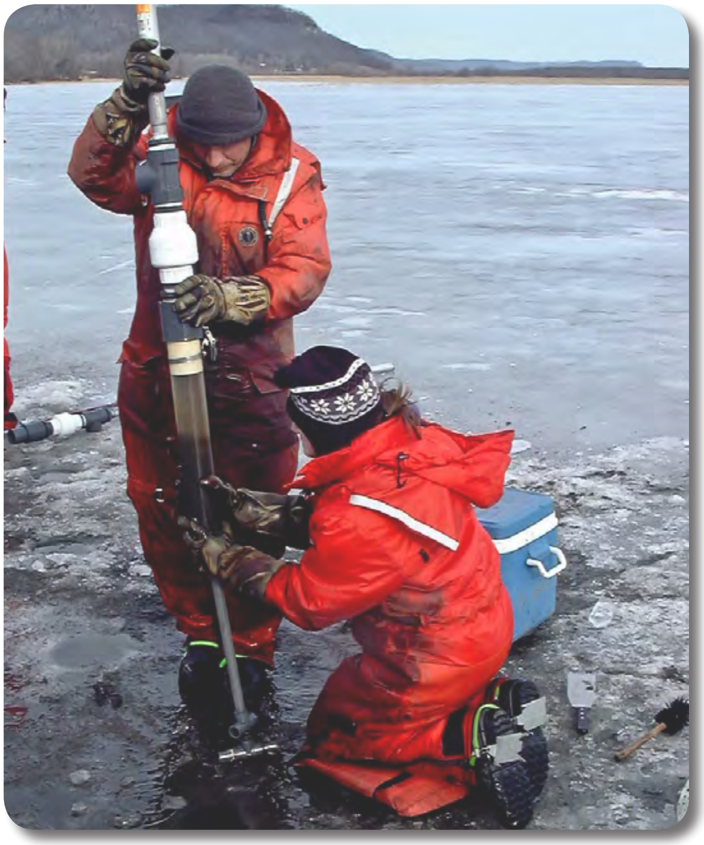
6.4. Learning and feedback

In adaptive management, the understanding gained from monitoring and assessment helps in selecting future management actions. It is the iterative cycle of decision making, monitoring, and assessment that leads gradually to better understanding of resource dynamics. As understanding evolves, so should decision making.

Several approaches to learning can be used; all involve using monitoring data to update confidence in the models under consideration. The enhanced understanding then guides decision making at the next time period. One common approach involves updating the measures of confidence associated with different models by combining them with current monitoring data via Bayes' rule to produce new confidence measures for the next time (Lee 1989).

One can think of the iterative learning cycle as starting with a management decision, followed by post-decision monitoring and the subsequent assessment of monitoring data, with feedback of what is learned into future decision making (Figure 2.3). Alternatively, one can think of the process as beginning with monitoring, followed by analysis of the resulting data, followed by decision making based on what is learned. In either case the sequence of activities is repeated over the course of a project, during which learning occurs and management strategy is adjusted accordingly.

Climate change. Climate change will create new challenges to learning, arising from the instability that climate change induces in patterns of resource change. The environmental variations defining climate change can influence the uncertainty factors in adaptive management (see Chapter 4) and produce deep uncertainties about resource dynamics and decision making. When the resource system itself is changing over time, learning-based decision making becomes especially difficult. One way to approach the problem is to use scenarios of different environmental futures, and learn about their relative adequacy by means of monitoring resource attributes and environmental conditions.



Water resources. Learning in water resource projects centers on structural uncertainty about hydrological processes and rates. Hydrological models that express structural uncertainty describe different trajectories for water conditions, flows, aquatic organisms, etc, which can be compared with actual states estimated from hydrological and other monitoring. Learning can be pursued with classical experiments according to a management design, or with sequential updating of model confidence using Bayes' rule.

Energy. Learning and feedback in energy projects relates to the impacts of siting, infrastructure development, and operation of energy facilities. At specific sites, project evaluation is often based on monitoring data used in Bayesian updating of model weights, resulting in better understanding that can be applied to future management decisions about operations. In larger-scale evaluations, information and understanding from one site can be applied to other sites to guide development as they are being established. In either case, what is learned is folded into future decision making.

Human/natural interface. Learning in this context is often based on interventions replicated over time rather than space, because many projects involve animals or plants in the wild and occur at scales that don't allow replication in space. That said, some problems are more amenable to spatial rather than temporal replication, for example, large-scale management of old-growth forests in which responses to management interventions occur after long time lags. In both instances the data produced by monitoring can be used to assess the system responses to management over time, with new understanding used to adjust management.

Examples of learning and feedback

New England shrub habitats on refuges

Shrub communities on wildlife refuges in the northeast support migrating land birds and the New England cottontail rabbit, a candidate for listing under the Endangered Species Act. Fish and Wildlife Service managers use adaptive management to control the invasive plants that degrade native shrub communities. Learning is promoted by updating credibility weights of two competing models of low- and medium-intensity treatments of invasive plants on the basis of monitoring data. The two models differ in how much effort is needed to restore native shrub communities successfully. The data also can be used to refine the models and improve parameter estimates. What is learned in the project will be relevant to the choice of treatments for shrub habitat management in other coastal areas in New England.

Native prairie restoration in national wildlife refuges

Native prairies in national wildlife refuges of the northern Great Plains are being invaded by plants such as smooth brome and Kentucky bluegrass as a result of the suppression of natural disturbance. Managers choose annually among alternative treatments to restore a high proportion of native species. Environmental variability across spatial and temporal scales compounds the inherent difficulty of choosing the best management action to reach established restoration targets. Uncertainty is represented by a set of four competing models that express alternative

hypotheses about vegetation responses to management. The annual cycle involves treatment, monitoring, and assessment of data against model-based predictions of prairie responses. The credibility weights of the models are revised annually with monitoring data and used to identify an optimal action for the following year. Information on vegetation response and actions implemented is added to a permanent database that can be used for evaluation and periodic revision of the predictive models.

Adaptive harvest management

Adaptive harvest management was developed to deal with uncertainties in the regulation of sport waterfowl hunting in North America. Each year, a proposed policy for waterfowl hunting regulations is derived by dynamic optimization methods. After regulatory decisions based on this policy are made, model-specific predictions for subsequent breeding population size are compared with monitoring data as they become available, to produce new model credibility weights with Bayes' rule. The process is adaptive in the sense that the harvest policy "evolves" over time to account for new knowledge generated by the comparison of predicted and observed population sizes. The change in harvest policy from 1995 to 2007, resulting from changing model weights, is a striking example of the efficacy of adaptive management as it is actually implemented.

Great Barrier Reef marine reserve management

The Great Barrier Reef is a 2,000-kilometer-long complex of coral reefs and other ecosystems such as coastal seagrass beds and diverse sea-floor habitats covering 135,000 square kilometers off the northeast coast of Australia. It is a national marine park that contains the world's largest network of marine reserves, which are designed systematically at a regional scale. Adaptive management is used to restore ecosystem structure (e.g., widespread recovery of depleted fish stocks) and to prevent ongoing degradation (e.g., reduced coral mortality). The Great Barrier Reef Zoning Plan 2004 protects living marine resources including apex predators (reef sharks) and commercially fished reef species (coral trout, redthroat emperor) with different levels of zoning. Monitoring is used to evaluate effectiveness of management strategies in meeting objectives (e.g., by comparing conditions before and after zoning implementation, or replicates across a range of zones or other gradients), as well as effectiveness of enforcement. For the objective of restoring ecosystem structure, monitoring of juvenile and adult fish to estimate species population demographics has shown significantly greater reproductive output and transport of larvae of coral trout and redthroat emperors from no-take zones compared with fished zones, thus indicating that the no-take network provided ecosystem-wide population increases for recovery of fish stocks. Surveys of reef sharks showed higher abundances in no-entry zones than in no-take zones, which suggested possible compliance problems requiring further management action in no-take zones. For the objective of preventing degradation, monitoring of crown-of-thorns starfish (the major historical cause of coral mortality) and coral cover has shown strong positive connections among no-take reserve zones, reduced starfish outbreaks, and reduced coral mortality, thus indicating that zoning benefits the entire reef ecosystem.

6.5. Institutional learning

Periodically we may need to interrupt the technical cycle of decision making, monitoring, assessment and feedback, in order to reconsider project objectives, management alternatives, and other elements of the set-up phase. This reconsideration constitutes an institutional learning cycle that complements, but differs from, the cycle of technical learning. In combination, the two cycles are referred to as "double-loop" learning. By recognizing uncertainty about the architecture of decision making and allowing for reduction of that uncertainty over time, the institutional learning cycle expands the possibilities for learning in adaptive management. Important considerations are the frequency of revisitation of the set-up elements, which elements to revisit, how to recognize the need for adjustments, and the type of adjustments to be made.

In practice, the cycle of technical learning occurs more rapidly than that of institutional learning, with the institutional cycle producing less frequent changes of the set-up elements. Changes of objectives, management alternatives, and other elements that are too frequent can compromise both institutional and technical learning, by confounding their effects (Williams 2010*a*).

In many adaptive management projects, both kinds of learning are important. It is sometimes as useful to understand and track evolving social and institutional relations and stakeholder perspectives as it is to resolve technical issues about resource structure and process (Williams 2006). Although adaptive management can improve resource management by reducing structural uncertainty, the improvement can be stalled if social and institutional changes, which are inevitable over time, are not taken into account. Because early successes in achieving objectives can result in social and institutional changes, it is important to acknowledge and if possible account for them as decision making progresses.

Climate change. The uncertainties associated with climate change, in which directional changes in environmental conditions induce unstable (non-stationary) resource dynamics, are sure to offer many opportunities for double-loop learning. As the direction and magnitude of environmental change are revealed by monitoring environmental conditions, adjustments are likely to be needed in the models, alternatives, and even objectives, so that the decision making elements can be "recalibrated" to the patterns of systemic change.

Water resources. The multiplicity of values and perspectives that enter into adaptive decision making about water resources heightens the potential for change in the set-up elements. In particular, the pressure to change objectives can increase as monitoring data begin to reveal unexpected patterns in resource responses to water management. For example, a dam project that is managed for irrigation and power generation might reveal steadily declining native fish populations that require additional modeling and assessment. More generally, the potential for building up disproportionate benefits or costs among stakeholders can lead to revision of the management objectives for a project, or at least changes in weighting their relative importance. This in turn can lead to revising alternatives, monitoring protocols, or other elements.

Energy. Double-loop learning can play an important role in renewable and non-renewable energy projects. For example, decisions about the siting of facilities might meet initial objectives but nevertheless lead to an acknowledged need to consider other factors in decision making. Likewise, it may become clear over time that key aspects of facilities support and operations were not included in initial planning, or important stakeholders were not included, or stated objectives weren't adequate for evaluation and decision making. Under these circumstances the decision-making apparatus of adaptive management can be revised by changing the set-up elements.

Human/natural interface. Adaptive management projects in this field often need to change project objectives and projection models. As evidence of resource responses to management accumulates, stakeholders may revisit objectives and other elements in an effort to make strategies more responsive to their needs. As mentioned above, it is important not to change the set-up elements too frequently because rapid change can interfere with the rate of both technical and institutional learning.

Examples of institutional learning

Blanca wetlands

The Blanca Wildlife Habitat Area in southern Colorado is an area of over 6,200 hectares of marshes, ponds, and periodically flooded basins called playas, which provide habitat for a wide variety of wildlife and plant species. The 1995 management plan for this area

focused on a core area of 1,100 hectares for which the Bureau of Land Management has adequate artesian water. Since then, Bureau managers have learned that playa basins should be flooded only once every 3 to 6 years in order to produce the very high densities of the insects and vegetation critical for wetland birds. After revisiting the management alternatives, managers now are attempting to mimic the historic hydrology of playas by drying larger areas rather than individual basins. This involves rotation of the limited artesian water around an expanded area over multiple years, so that the longer drying times correspond to the natural hydrology of playas. Revised objectives place more emphasis on supporting shorebird populations because, as other wetlands in the region have been lost, Blanca has become the most important shorebird area in the San Luis Valley.

Northwest Forest Plan

The 1994 Northwest Forest Plan for federal lands in the range of the northern spotted owl formally established a regional effectiveness monitoring program with a feedback process using a 10-year interpretive report. The final report included a synthesis of new science and results from five monitoring modules, with direct participation by top interagency decision makers. An important lesson learned was that the belief held by most people that monitoring results would be clear and easily applicable in future decision making is incorrect, at least with raw data. The findings suggest that monitoring data can be used more effectively in an adaptive learning cycle when they are given a management context and assessed through structured interactions between researchers and decision makers. Recognition of the importance of assessment and an increased emphasis on it has led to changes in the framing of adaptive forest planning and management.

Adaptive harvest management

Adaptive harvest management was developed to deal with uncertainties in the regulation of sport waterfowl hunting in North America. Perhaps one of its greatest contributions is a capacity for managers to re-examine their purposes and rules of operation. The periodic examination of adaptive management components has usually been precipitated by an institutional recognition that current elements and protocols are inadequate to address unanticipated problems arising in management policy. For example, difficulties have arisen in recent years in defining unambiguous harvest objectives, in predicting and regulating harvests, and in coping with the tradeoffs inherent in managing multiple stocks of waterfowl exposed to a common harvest. The key challenge facing harvest management is whether the decision making structure of adaptive harvest management can itself be adaptive, that is, whether the knowledge and experience gained in its application can be reflected in higher-level structural adjustments when needed. Sorting out these policy and institutional issues will require innovative mechanisms for producing effective dialogue and new ways of handling disputes within a process that all parties regard as fair.

Columbia River chinook salmon

Dams that have been established on the Columbia River for hydropower, irrigation, and flood control have adversely affected spawning and recruitment of fall-run chinook salmon. Public utility districts of the middle Columbia River work with federal and state agencies and Native American tribes to set priorities for power generation and fish and wildlife protection. Dam relicensing by the Federal Energy Regulatory Commission highlighted the need to protect chinook spawning areas in the Hanford Reach of the Columbia. An adaptive management working group representing the stakeholders therefore established a procedure for water releases to minimize the risk that breeding areas would dry out from water fluctuations in the river, within the constraint of meeting energy demands. After implementation of the initial hydropower plan, follow-up monitoring revealed that once chinook

fry emerged from the breeding areas, they remained in the natal areas and did not move as those areas dried out under a post-breeding flow regime. This left juveniles stranded and perishing in large numbers, and threatened the gains realized by protecting spawning grounds in the fall. The working group established flow bands that took into account the volume of water being released from Grand Coulee Dam upstream, and suggested limits on the range of possible flows. This expanded the water release agreement to cover a longer time period from spawning through rearing. By altering the management options on the basis of monitoring in the Hanford Reach, the working group used double-loop learning to accelerate progress in achieving the objective of increasing chinook reproductive success.